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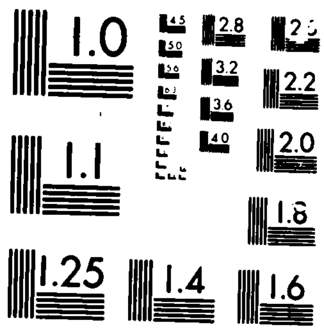

MICROCOPY RESOLUTION TEST CHART

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DNA-TR-85-187

THE UTILIZATION OF EMERGING TECHNOLOGIES IN PHYSICAL SECURITY SYSTEMS, PHASE IV, FIELD TEST SYSTEM DEMONSTRATION

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5 June 1985

Technical Report

CONTRACT No. DNA 001-83-C-0199

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SECURITY CLASSIFICATION OF THIS PAGE

REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188
Exp. Date: Jun 30, 1986

1a. REPORT SECURITY CLASSIFICATION: UNCLASSIFIED

1b. RESTRICTIVE MARKINGS:

2a. SECURITY CLASSIFICATION AUTHORITY: N/A since Unclassified

2b. DECLASSIFICATION/DOWNGRADING SCHEDULE: N/A since Unclassified

3. DISTRIBUTION/AVAILABILITY OF REPORT: Approved for public release; distribution is unlimited.

4. PERFORMING ORGANIZATION REPORT NUMBER(S): GRC-CR-85-1362

5. MONITORING ORGANIZATION REPORT NUMBER(S): DNA-TR-85-187

6a. NAME OF PERFORMING ORGANIZATION: General Research Corporation

6b. OFFICE SYMBOL (If applicable):

7a. NAME OF MONITORING ORGANIZATION: Director, Defense Nuclear Agency

6c. ADDRESS (City, State, and ZIP Code): P. O. Box 6770, Santa Barbara, CA 93160-6770

7b. ADDRESS (City, State, and ZIP Code): Washington, DC 20305-1000

8a. NAME OF FUNDING/SPONSORING ORGANIZATION:

8b. OFFICE SYMBOL (If applicable):

9. PROCUREMENT INSTRUMENT IDENTIFICATION NUMBER: DNA 001-83-C-0199

8c. ADDRESS (City, State, and ZIP Code):

10. SOURCE OF FUNDING NUMBERS

PROGRAM ELEMENT NO	PROJECT NO	TASK NO	WORK UNIT ACCESSION NO
62715H	B99QMXP	F	DH008446

11. TITLE (Include Security Classification): THE UTILIZATION OF EMERGING TECHNOLOGIES IN PHYSICAL SECURITY SYSTEMS, PHASE IV, FIELD TEST SYSTEM DEMONSTRATION

12. PERSONAL AUTHOR(S): Bartek, R. J., Packard, L. W.

13a. TYPE OF REPORT: Technical Report

13b. TIME COVERED: FROM 830401 TO 840831

14. DATE OF REPORT (Year, Month, Day): 850605

15. PAGE COUNT: 72

16. SUPPLEMENTARY NOTATION: This work was sponsored by the Defense Nuclear Agency under RDT&E RMSS Code B248085466 B99QMXPF00012 H2590D.

17. COSATI CODES

FIELD	GROUP	SUB-GROUP
5	10	
15	3	

18. SUBJECT TERMS (Continue on reverse if necessary and identify by block number): Intrusion; Nuisance Alarm; Retrain; Poll; Loopback

19. ABSTRACT (Continue on reverse if necessary and identify by block number)

A three-node single-loop intrusion detection system was constructed and set up in a laboratory at GRC's McLean facility. A sensor field containing RACON, MILES, and SPIR sensors, as well as several geoplanes, was installed by WES at that facility, and the sensors were connected to the system so that test data could be collected and the performance of the system measured.

The pattern classifier (Adaptive Learning Network or ALN) used in the system was originally trained on data collected at Eglin Air Force Base. With that ALN in the system, tests were run at GRC. During the testing, the system maintained a Pd of .974 and a Pna of .070 where large dogs, approximately human weight, were primarily used as nuisances.

20. DISTRIBUTION/AVAILABILITY OF ABSTRACT: ☐ UNCLASSIFIED/UNLIMITED ☒ SAME AS RPT ☐ DTIC USERS

21. ABSTRACT SECURITY CLASSIFICATION: UNCLASSIFIED

22a. NAME OF RESPONSIBLE INDIVIDUAL: Betty L. Fox

22b. TELEPHONE (Include Area Code): (202) 325-7042

22c. OFFICE SYMBOL: DNA/STTI

DD FORM 1473, 84 MAR — 83 APR edition may be used until exhausted. All other editions are obsolete.

SECURITY CLASSIFICATION OF THIS PAGE
UNCLASSIFIED

PREFACE

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SECTION 1
INTRODUCTION

This report marks the completion of the fourth phase of activity on an advanced physical security system for DNA. Phases I and II were devoted to demonstrating the feasibility of using distributed processing, adaptive learning networks (ALNs), and fiber optic communication links in such a system. Phase III was devoted to the design and fabrication of a laboratory prototype system using "off-the-shelf" technology. During Phase IV, a three-node single-loop prototype system was developed which was used to demonstrate operation and which was be shown to meet performance goals. These goals were:

1. Have a low false alarm rate (<0.1), while maintaining a high probability of detection (>0.9).

2. Be site adaptable.

3. Have a response time of one second or less.

The first two goals were achieved by using multiple sensors, and by using ALNs to perform multi-sensor integration. (Site-specific adaptibility can be further enhanced by training the ALNs on a data base collected at the site of interest). The third goal was met by distributing the processing and by using a fast single-board array processor for the more time consuming operations.

This report is divided into seven major sections. Section 2 states conclusions and recommendations. In Section 3, the system that was planned for Phase IV is outlined. Section 4 describes major problems encountered during Phase IV, and the system configuration at the end of Phase IV. In Section 5, field testing and system performance are discussed. Section 6 presents a system level description of the Physical Security System as it is envisioned at the beginning of Phase V. The final section, Section 7, describes plans for this next portion of work.

SECTION 2
CONCLUSIONS AND RECOMMENDATIONS

As a result of the activities of Phase IV, the following conclusions have been arrived at:

- The feasibility of an intrusion detection system utilizing distributed processing, fiber optic communication, and ALNs for pattern classification has been demonstrated.

- The system goals for detection probability, false alarms, and response time have been met or exceeded.

- A first indication has been obtained that the ALN trained on data from one site is portable to other sites.

It is recommended that the next phase of work include the following goals:

- The present system design should be upgraded to include new and improved components where such components are now available.

- A complete dual-loop three-node system should be developed which can be moved to various sites to further test portability.

- A ten node system should be developed which can be located on a semi-permanent basis at a single site for long-term testing.

- The multi-sensor technology of the ALNs should be extended to other types of security systems.

Detailed requirements for implementing the first two of these recommendations are included in Section 7.

SECTION 3
PHASE IV SYSTEM CONCEPTS

The system, as it was envisioned for Phase IV, is described in this section. The design goals were a low nuisance alarm rate (<0.1) and a high probability of detection ($>.9$). The system was to be site-adaptable, and to have a response time of less than one second.

Discrimination between real and nuisance alarms was achieved by using higher order pattern classifiers. This signal processing technique makes use of algorithms which are trained to recognize intruders as well as other events such as vehicles, animals, weather phenomena and normal site activity. The training can also be adapted to site-specific conditions such as terrain variations and differing soil conditions.

Figure 1 shows the network architecture. The site perimeter is divided into sectors. Each sector has a set of sensors connected to an independent processing node. The nodes are arranged in a double ring topology, with data being transmitted in both directions simultaneously. The nodes communicate over a fiber optic link, by means of local area network controllers which are present in each node.

3.1 DISTRIBUTED PROCESSING

Three types of nodes perform the system control and processing functions. The system control node serves as the operator interface and resides in the guard station. Each basic node monitors the sensors connected to it and performs the signal processing necessary for event detection. Each enhanced node services several basic nodes and performs the more detailed signal processing required for making classification decisions once an event has been detected.

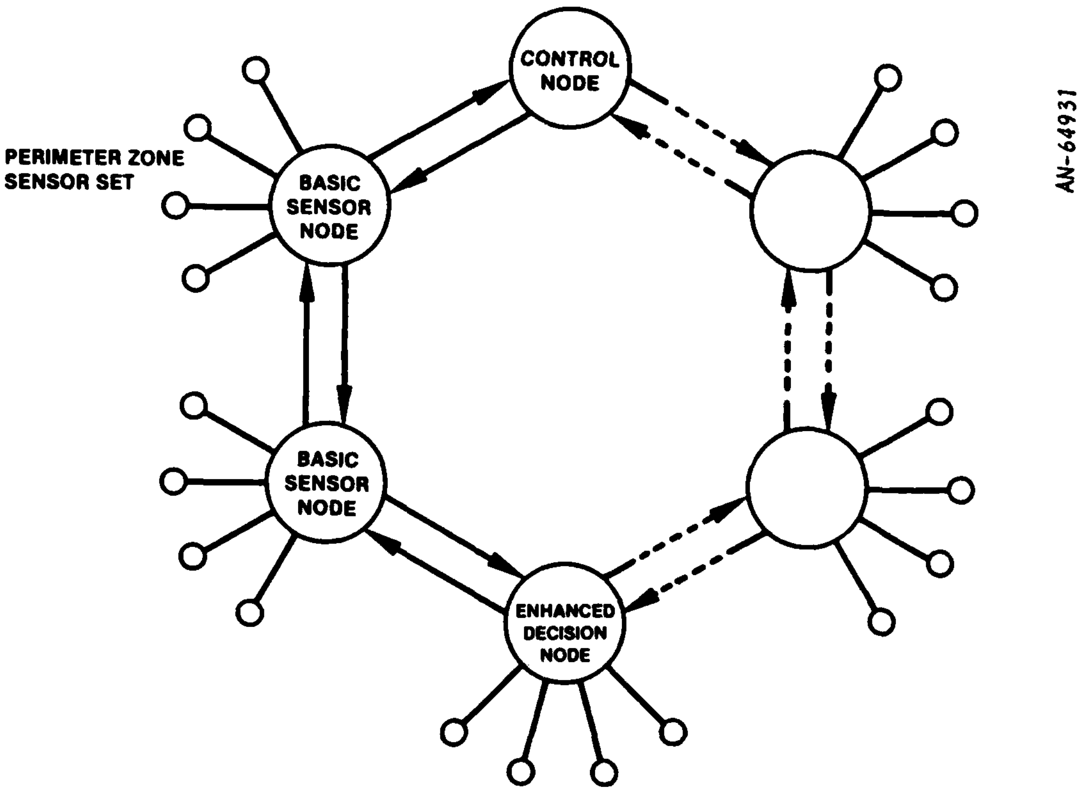

Figure 1. Network topology.

When a basic node determines that one of the sensor signal thresholds has been crossed, it sends the necessary data to the enhanced node that is assigned to it. The enhanced node then processes the data through the appropriate algorithms to determine whether the event should generate an alarm. If it does, the enhanced node sends that information to the system control node, which then displays an alarm screen and prompts the guard for action. This data acquisition and classification processing occurs in near real time, that is, less than one second from the beginning of an event.

Each basic node performs the following functions:

- o It provides analog signal conditioning for one or more sets of active sensors.
- o It provides analog to digital conversion of sensor signals.
- o It performs intrusion detection.
- o It calculates time domain features from sensor signals.
- o It sends features and raw data to and receives messages from other nodes in the network.
- o It performs backup processing for an adjacent sector.

Each enhanced node consists of a basic section, which performs all the functions listed above, and an enhanced section, which performs the following functions:

- It receives time-domain features from several basic nodes.
- It receives sensor signal waveforms from several basic nodes.
- It calculates frequency domain features from sensor signals.
- It combines time and frequency domain features in an ALN to make an alarm decision.
- It notifies the system control node if an alarm has occurred.

The control node performs the following functions:

- It processes and displays alarms.
- It displays a graphic presentation of alarm locations.
- It prompts the operator with instructions for responding to alarms.
- It allows definition and configuration of the network architecture.
- It initializes the system.
- It controls all system communication.
- It monitors system health.
- It reconfigures the system upon node/cable failure.
- It maintains a system log.

- It stores alarm data.

- It retrains the system.

3.2 COMMUNICATIONS

The nodes are connected by fiber optic cables in a double ring topology. This creates two redundant message channels, with messages being transmitted simultaneously in both directions at 1.5 Mbits/sec. Each message travels completely around the ring and is removed from the ring when it reaches the original sender. When a message arrives at a node, it is repeated to the next node, and simultaneously decoded by the present node to determine whether it is the message's destination.

Network control is handled by polling under the direction of the system control node. The Local Network Control (LNC) boards in that node are configured as masters, and all others are configured as slaves. The *master* LNC boards use a polling list to determine the sequence in which they poll the nodes, and the amount of time allotted to a node during which it may start a transaction. If a node finishes with a transaction before that amount of time has elapsed, it notifies the master and relinquishes the poll, thus allowing the next node in the polling list to be serviced. Messages may be sent directly by any node to any other node in the network. If one of the nodes needs more attention than another, it may occur repeatedly in the polling list.

The dual loop system allows for loopback action when one of the nodes fails or when there is a break in the fiber optic link. This reconfiguration produces a single loop which preserves signal continuity, and which allows the network to remain operational.

The goal of Phase IV was to develop a physical security system containing one each of three distributed processing nodes; the control

node, the enhanced node, and the basic node. All software for signal processing, for communications, for decision making, for data storage and for system control were to be operational. Time domain processing was to be accomplished on the MILES cable, the SPIR cable, the RACON sensors, and frequency domain processing was to be done on one of five geophones. All of these features are important for overall system operation, but some do not contribute directly to performance measure, that is, detecting intruders with a probability greater than .9, rejecting greater than 90% of the false intruders and making these decisions in less than one second.

As Phase IV developed, it became obvious that these goals were overly ambitious. This situation was made more critical when some of the system hardware proved to be unreliable, and customer support for that hardware was difficult to obtain. Thus, the goals of Phase IV were resealed to provide a system with all of the components needed to demonstrate that system performance, as defined in the opening paragraph of Section 3, could be met under field conditions. The problems which drove this decision and the system modifications are detailed in the paragraphs which follow. Consequently, many of the functions, which are listed in Section 3.1, were not completed, or were completed and not tested.

SECTION 4
FINAL PHASE IV SYSTEM

This Section details the problems which drove the decision to develop only those portions of the system necessary to demonstrate performance and the resulting system modifications.

4.1 THE WICAT SYSTEM

The Wicat system was originally selected because of its Multibus compatibility. However, in practice it has proven not be totally compatible, and it can handle no more than one bus master at a time. Since the local area network controllers and the Winchester disk-controller residing within the control node are both bus masters, only a single loop, non-archiving system could be implemented. In spite of the inability to archive, the system could still collect and process data in real time, and the system's ability to meet the performance goals could be measured. During Phase V, it is planned to replace the Wicat system with an IBM-PC, and the previously mentioned operational limits should be removed.

4.2 FIBER OPTIC MODEM

The fiber optic modems operate via a phase lock loop. Moderate effort was required to design a system which would allow communication between nodes operating at slightly different clock rates. So that performance could be measured, only a single loop modem was designed and implemented. However, dual loop modems have also been designed, and will be implemented during Phase V. For a backup system, coaxial point-to-point modems are also available for testing and data collection purposes.

4.3 FREQUENCY DOMAIN FEATURES

The plan at the beginning of Phase IV was to implement and test both frequency and time domain ALNs. Preliminary tests were conducted, using features from each of these domains, which indicated that the time domain system provided slightly better performance then the frequency domain. Thus, a decision was made to first activate the time domain ALN within the system.

Driver software was written for the frequency domain, but was not debugged or tested. This is planned to be completed during Phase V, since the frequency domain option will allow additional system flexibility. (Note, however, that zero crossings per second is one of the time domain features, and this feature is a pseudo frequency feature.)

4.4 SIGNAL CONDITIONING

The analog signal conditioners and filters were physically modified from the original design to comply with Multibus packaging standards so that these circuits could utilize the Multibus enclosures and supplies. This change reduced size and power consumption of both remote nodes.

4.5 THE FINAL SYSTEM

The system which was taken into the field for the performance testing is shown in Figure 2. It consisted of three operational nodes capable of processing data from three sensors. Processed data from the system were recorded on a stripchart recorder. The hardware which implements this system is listed in Table 1.

4.6 SYSTEM SOFTWARE

Software operates out of RAM in the control node, and out of a combination of RAM and ROM in the basic and enhanced nodes. The basic and enhanced software is downloaded into RAM from the control node via the communication loop when the system is activated. The downloaded code is primarily assembler and the control node code is primarily Pascal. The control node operating system, Wicat's MCS, and all system support software is supplied by Wicat.

The software developed by GRC during Phase IV is listed in Table 2 below. That portion of the software which was exercised during the testing is indicated with an asterisk.

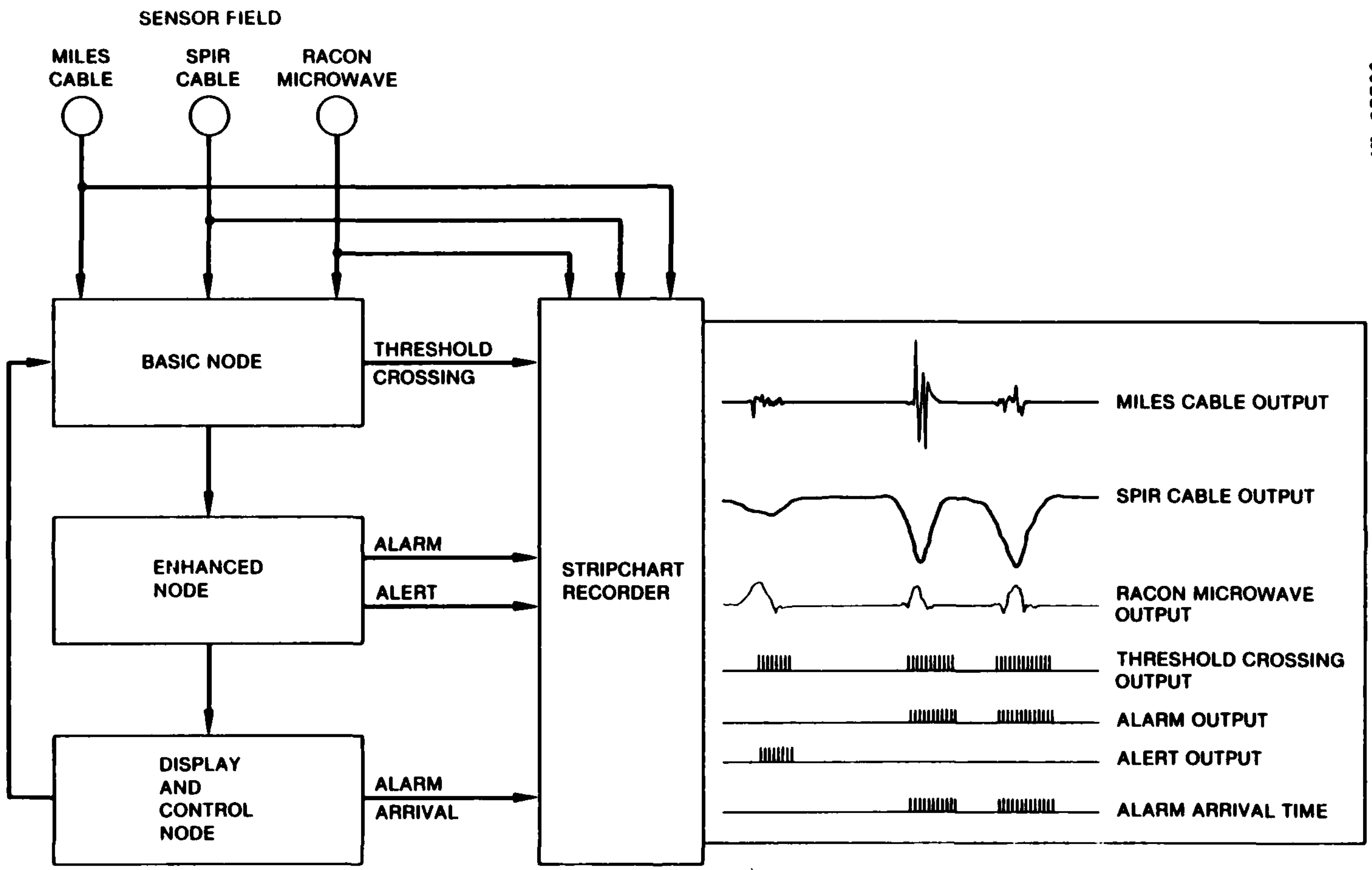

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Figure 2. Field test demonstration system.

Table 1. Phase IV hardware.

BASIC NODE

- Intel 86/30 Single Board Computer
  - Intel SBX Analog to Digital Converter Board
  - 128K RAM
- Interphase Local Network Controller
- Fiber Optics Modem

ENHANCED NODE

- Two Intel 86/30 Single Board Computers
  - 8087 Arithmetic Co-Processor
  - Intel SBX Analog to Digital Converter Board
  - 128K RAM, (each computer)
- Interphase Local Network Controller
- Fiber Optics Modem

CONTROL NODE

- Wicat 150WS
  - Motorola 68000 Microprocessor
  - 512K of MOS RAM
  - Floppy Disk Drive
  - 10 Megabyte Winchester Disk Drive
  - Medium-Resolution Green Phosphor Display
- Interphase Local Network Controller
- Fiber Optics Modem

Table 2. Phase IV software.

COMMUNICATION CONTROL SOFTWARE

Transmit*
Receive*
Dual Loop Communication
Loopback
Remote Node Health Check*

RECONFIGURATION SOFTWARE

Number and Type of Nodes*
Sensor Types
Threshold Settings*
ALN Settings
Geography and Environment

DOWNLOADING SOFTWARE

Operational Checks*

DISPLAY SOFTWARE

Alarm Screen*
Archiving (Alarm Goundtruths)
Archiving (Signal Data)
Perimeter Map Screen*

SECTION 5
FIELD TESTING AND SYSTEM PERFORMANCE

A sensor field was installed in August of 1982 near the GRC, McLean facility. The layout and installation were under the direction of Waterways Experiment Station personnel, and the field was designed to be similar to the BISS sensor field installed at Eglin Air Force Base. The field, shown in Figure 3, contains a MILES cable, a SPIR cable, RACON sensors, and geophones. (The geophones were not used in the system testing.)

The primary objective of the tests was to measure the detection performance of the system. Before this could be done, however, it was necessary to repair and modify parts of the test field and to calibrate the sensors.

5.1 FIELD ADJUSTMENTS

Repairs and modifications to the DNA test field electronics were necessary to obtain sensor signals which were compatible with the front-end and also to reduce line interference to a tolerable level. More specifically, the modifications included re-grounding and the addition of a differential line driver to the MILES sensor. Repairs included location and reconnection of severed SPIR coax cables, and repair of the RACON receiver which had been damaged by vandals.

The sensor field layout was physically divided and marked into 32 equally spaced zones (Figure 3). This was to assist in characterizing sensitivities as a function of displacement along the sensor path. Several iterations of this activity were required in order to obtain a reasonably accurate picture of the overall field sensitivities. The process began with human crossings through every zone of the field while

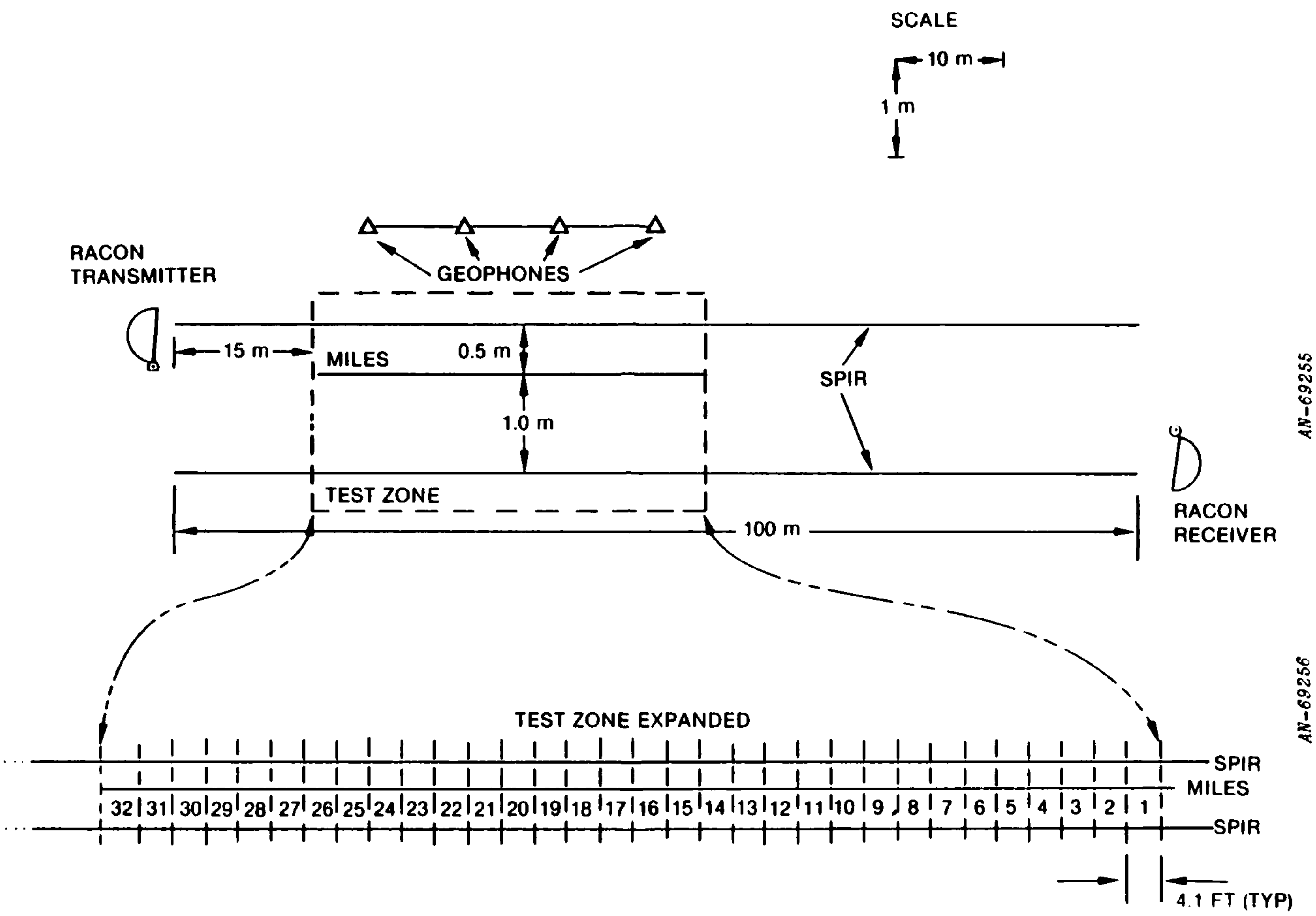
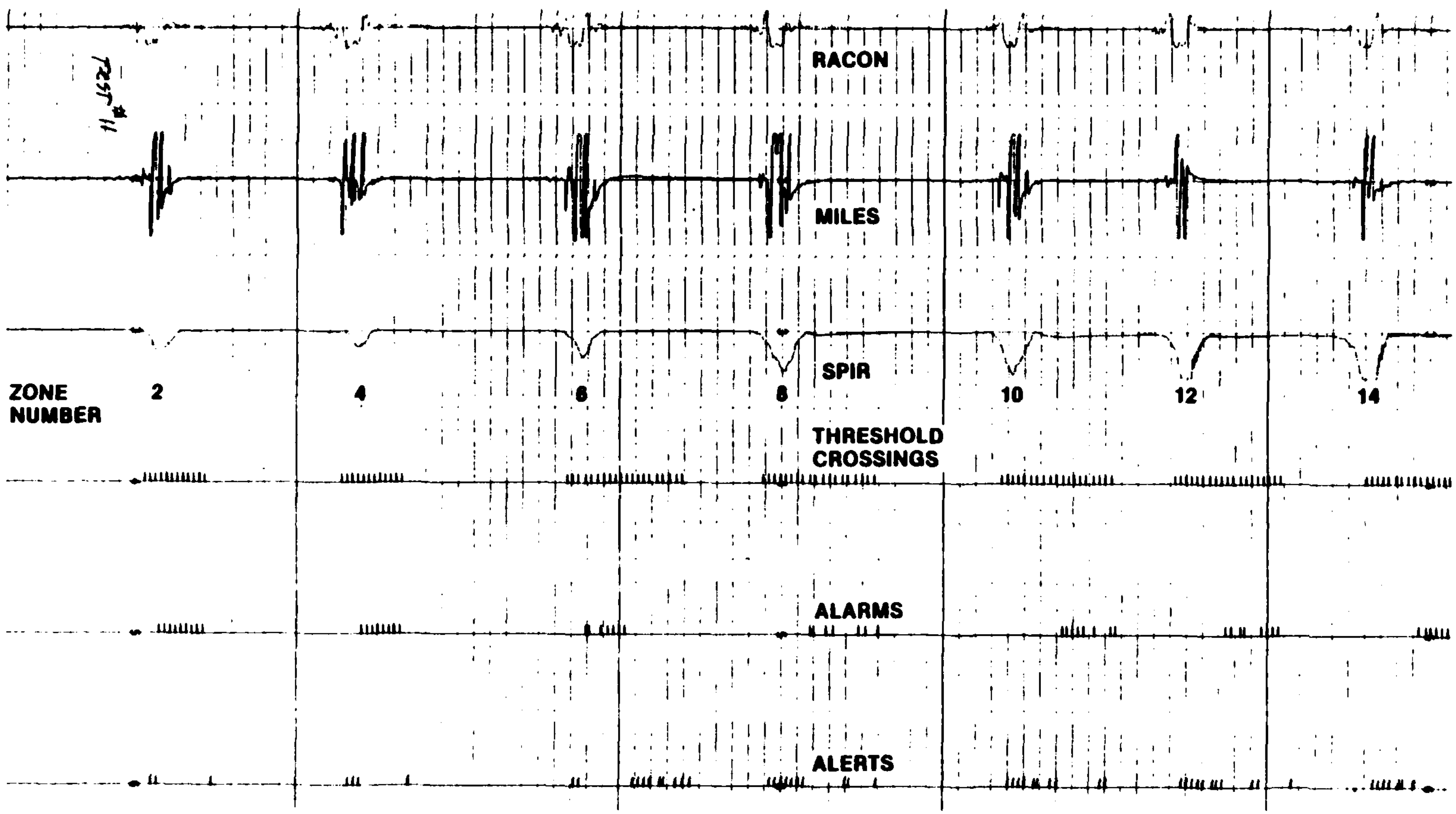


Figure 3. McLean sensor field layout.

attempting to keep changes (speed, direction, mass, etc.) at a minimum. The sensor outputs were recorded on a stripchart recorder so that comparisons and adjustments could be implemented. Sensor sensitivity nulls in several zones were discovered and noted. Initial sensor gains were a 'best guess' estimate derived from previous experience with prerecorded analog sensor data taken at the BISS field test site, Eglin AFB. The purpose of this 'rough' calibration exercise was to get to a point at which the optimization procedure for the entire system, including the ALN software, could begin.

A typical stripchart recording from one of these calibration tests is shown in Figure 4. Since there was snow on the ground at the time of this test, the crossings could be made, in almost identical fashion, by duplicating the footprints from zone-to-zone. For these zone crossings, some variation can be seen in the MILES cable output, but the response variation from zone-to-zone in the SPIR cable is most striking.

Next, as much data was collected as was allowed by time and resource constraints. This involved extensive intrusion exercises using both human and animal targets. Many types of crossings were performed and recorded (running, crawling, etc.) under a variety of conditions (snow, rain, wind, etc.). This part of the testing exercise was the most interactive in that after a group of intrusions had been completed, the output of the system (Alarms and Alerts) was evaluated and its inputs (sensor gains and threshold levels) were incrementally adjusted toward more optimal values, and then the cycle was repeated. The goal was to adjust the system to achieve the lowest nuisance-to-real alarm ratio with a near 100% real alarm rate. As was stated earlier, the ALN in use was trained on data collected at the BISS field test site and it was unknown how transportable it was to a 'foreign' site. Since the system did not yet have the capability for retraining, one purpose for these exercises was to adjust the inputs to fit the ALN. When retraining is implemented, this task will be unnecessary as the ALN will adjust the



TEST #11

Figure 4. Typical calibration test sensor outputs.

algorithm to fit the inputs. As will be shown, the ALN appears to be fairly transportable at least between the two sites from which the data have been derived.

This period of testing also gave the opportunity to record and appreciate a few of the problems that arise from sensor sensitivity to non-animal effects. Mentioned above were the sensitivity variations of the MILES and SPIR sensors along their lengths. Also noted were variations in the RACON nominal output level with ambient temperature, and changes in the SPIR with soil moisture content.

5.2 TEST RESULTS

During the two-week period in March, 1984, over one thousand events were staged and recorded. An occurrence on one or more of the sensor outputs which meets or exceeds the energy threshold setting for that sensor, is classified as an event. Of these events, 767 were selected as statistically viable for evaluating system performance. Events not selected were classified as atypical in that they occurred during times when the system was grossly misadjusted, or the event itself was atypical, i.e., outside previous ALN experience. The majority of the selected events occurred during the latter portions of the tests when the iterative 'fine tuning' process had reached a plateau where further adjustments provided diminishing performance enhancement. The system was stimulated to produce events by physically crossing the sensor field either with human or animal (dog) intruders. All events were recorded on a stripchart recorder which included all sensor analog outputs, threshold crossings, alarm and alert discrete outputs, and the ALN-out-of-range discrete output. (This last output occurs when the examined event lies outside the event-history stored in the ALN for either intruders or non-intruders). For comparison purposes, the RACON sensor alarm output was also included in some of the stripouts.

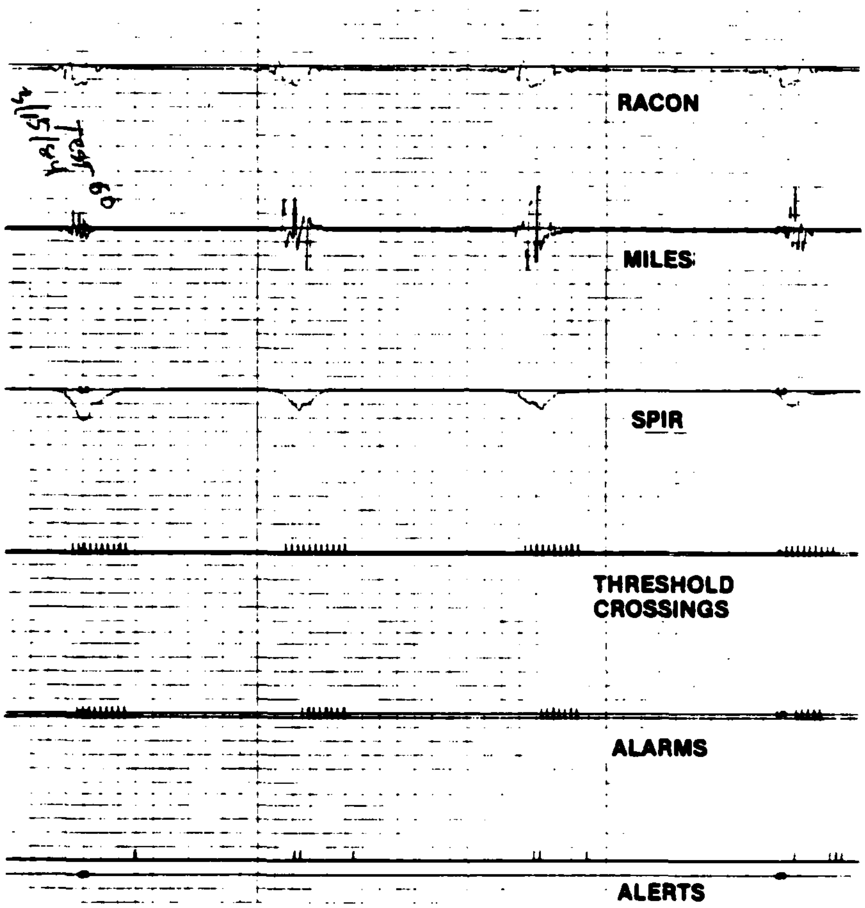
Table 3 lists the 26 tests which produced the 767 events used in the evaluation. The events are grouped as either real or nuisance occurrances. They are further broken down as to what the system calls were, i.e., real called real, real called nuisance, etc. Figures 5 and 6 are stripcharts of typical crossings of both human and animal targets along the length of the sensor field.

At this point, comparisons may be made between system performance using the Eglin test site data on which it was trained, and performance on the GRC test field. Results of this comparison, shown in Table 4 suggest that the algorithms developed using the Eglin data adapted well to the GRC test site without retraining.

Not all decisions made by the system were correct. Figures 7 and 8 show examples of slow or faulty decisions made by the system that might be improved by retraining. Specifically, Figure 7 shows two humans crossing the sensor field simultaneously at different oblique angles. Although the system does finally alarm, an elapsed time of 3 to 4 seconds occurs before the correct decision is made. The reason for the delay can be understood by visualising the ALN n-space feature surface division between real and nuisance alarms as not correctly formed to include the type of event such as shown in the stripout. The alarm may have occurred because the features moved outside the area of ALN experience (a situation which will alarm the system) and not because of moving into the previously trained area of recognized alarm conditions. Figure 8 is caused by a human intruder crossing the field at a particularly weak section of the SPIR sensor cable producing a signature slightly anomalous from other similar crossings. In the first crossing, the correct decision was delayed but is made. In the second crossing, however, the event is short lived enough for it to be misclassified completely. (The one second specification is more relevant to events which occur quickly, and is designed to allow time for visual sighting of an intruder. As long as the intruder is close enough to the sensor field

Table 3. Field test results.

INTRUSION TYPE	NO. OF EVENTS	REAL EVENT	NUIS-ANCES	REAL/ REAL	REAL/ NUIS.	NUIS/ NUIS.	NUIS/ REAL
Human Walking	10	10	0	10	0	0	0
Human Walking	6	6	0	6	0	0	0
Dog	12	0	12	0	0	11	1
Dog w/Handler	5	5	0	5	0	0	0
Human	28	28	0	28	0	0	0
Human	28	28	0	28	0	0	0
Dog	54	0	54	0	0	54	0
Dog w/Handler	26	26	0	25	1	0	0
Dog Running Angles	20	0	20	0	0	18	2
Human Walking	30	30	0	29	1	0	0
Dog	60	0	60	0	0	54	6
Dog w/Handler	30	30	0	30	0	0	0
Human Running	30	30	0	29	1	0	0
Human Walking	30	30	0	29	1	0	0
Dog	61	1	60	1	0	56	4
Dog	8	0	8	0	0	6	2
Dog	6	0	6	0	0	4	2
Dog	6	0	6	0	0	5	1
Dog	60	0	60	0	0	59	1
Human Walking	30	30	0	28	2	0	0
Human Running	30	30	0	27	3	0	0
Human Running	30	30	0	30	0	0	0
Dog	61	1	60	1	0	55	5
Human Walking	30	30	0	30	0	0	0
Dog	60	0	60	0	0	53	7
Dog	16	0	16	0	0	15	1
TOTALS	767	345	422	336	9	390	32



TEST #60

Figure 5. Human intruder crossings.

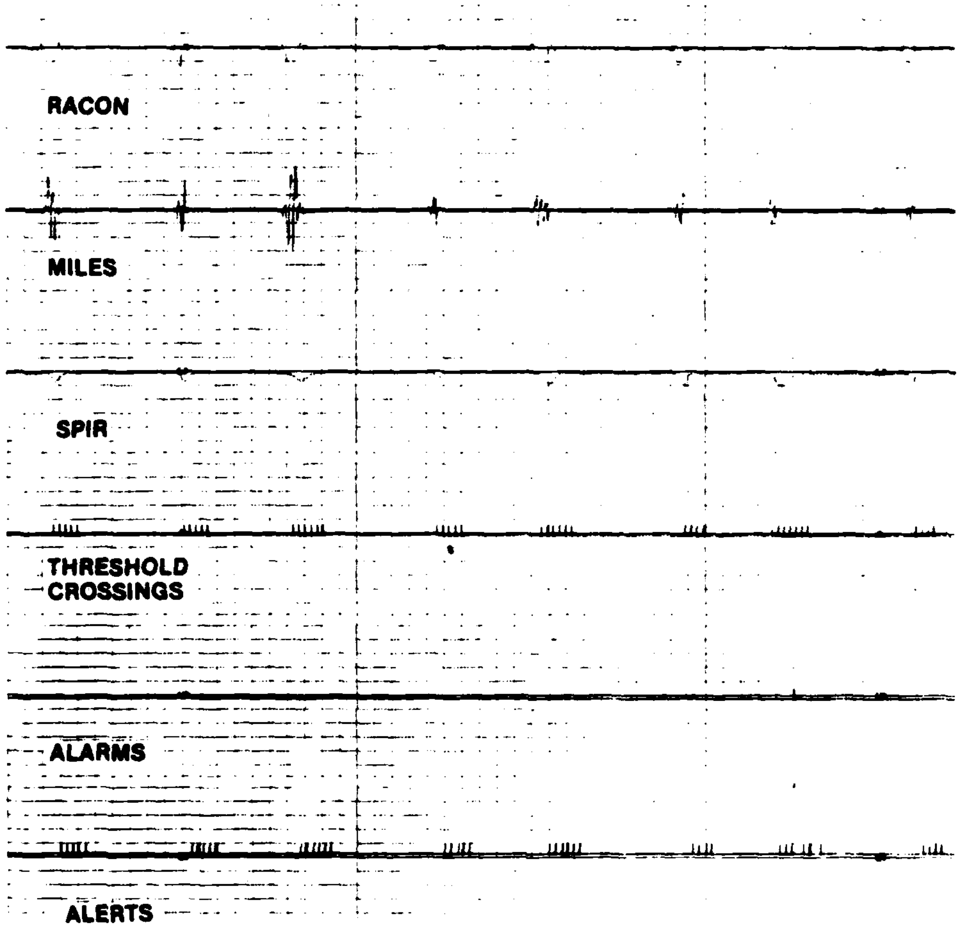


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Figure 6. Animal crossings (large dog).

Table 4. Field performance results.

TRUE \ CALLED	INTRUDER	NONINTRUDER
INTRUDER	0.989	0.011
NONINTRUDER	0.078	0.922

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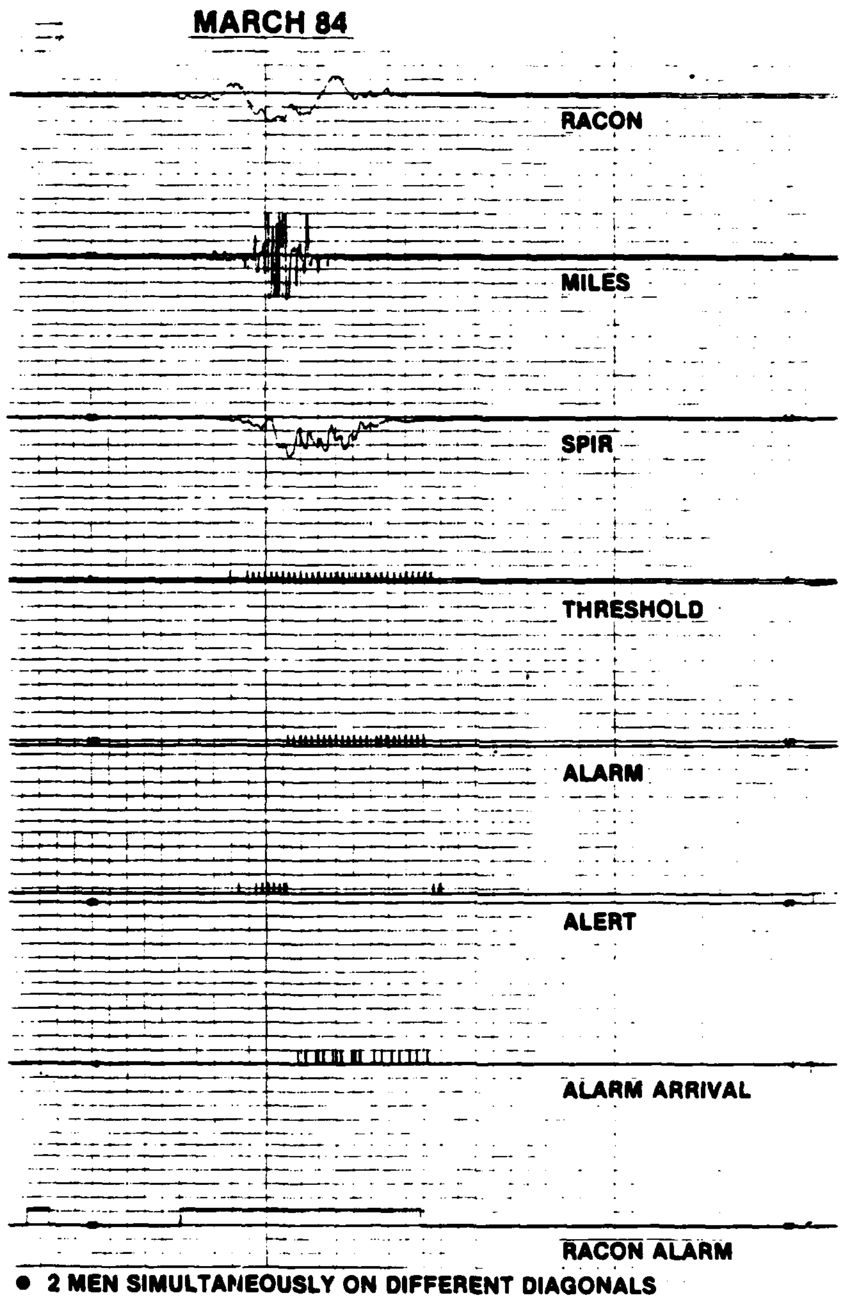


Figure 7. Two men crossing simultaneously on different diagonals.

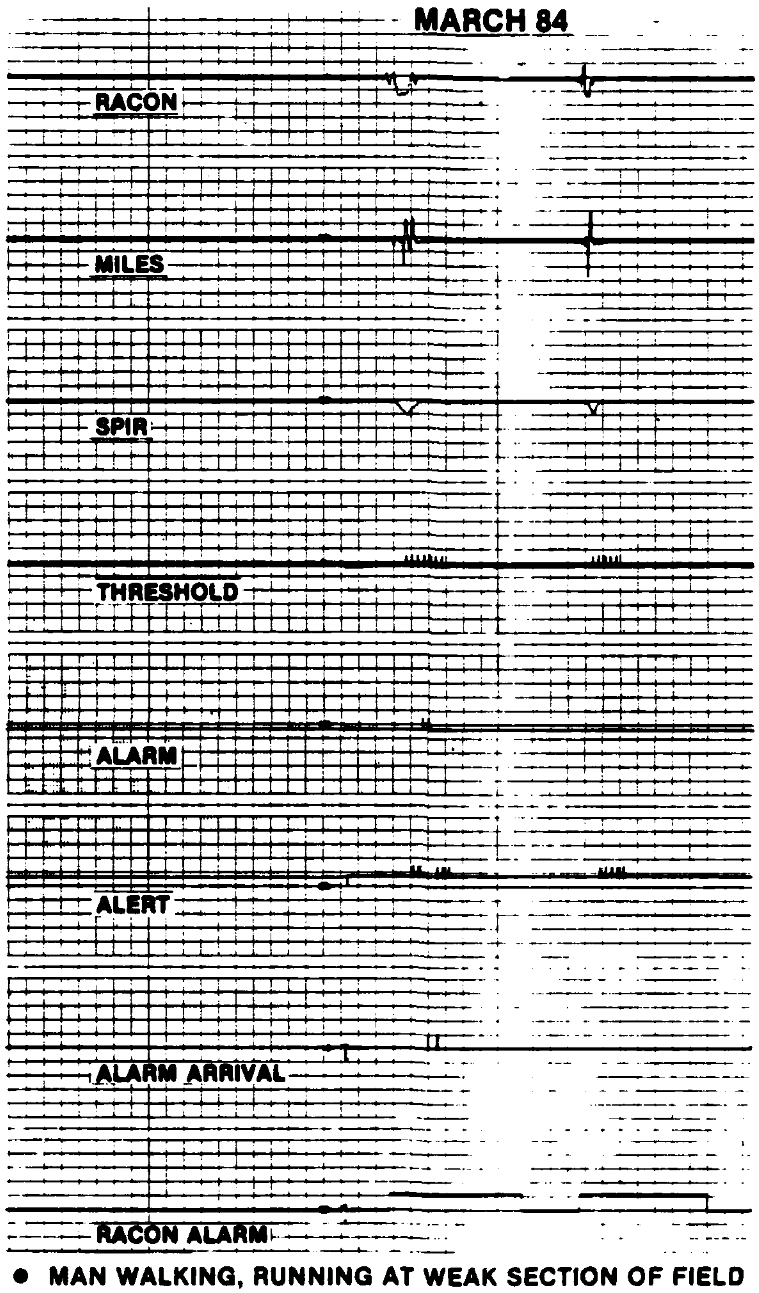


Figure 8. Man walking, running at weak section of the field.

to force signals in the sensors when the decision is made, this should still meet the criteria for "real-time".)

SECTION 6
PHASE V SYSTEM DESCRIPTION

6.1 SYSTEM OVERVIEW

This section of the Final Report describes the Phase V system in block diagram format. These block diagrams contain a mix of functional and hardware subsystems, the main purpose of these mixed diagrams being to explain the way in which the system will operate. The description begins with Figure 9, which is the overall system block diagram. The overall system has been divided into the front end, the signal processing, and the command and control, including inputs from the operator. Solid lines in Figure 1 indicate the flow of data, and dashed lines show where the operator has entry into the system. Each of the major subsystems is detailed in the following sections.

6.2 FRONT END

The front end, shown in Figure 10, includes sensors and conditioning. The portion labeled "sensors" is that part of the front end which can vary from installation to installation, and the portion labeled "conditioning" is that portion which is fixed in design, but with variable settings so that it can couple into a wide range of sensors and special circuits. The front end hardware will have input channels for eight double ended inputs, since it is anticipated that the sensors will always be connected in this fashion. Eight channels of conditioning circuitry will also be provided, and eight monitor inputs will also be available. These monitor inputs can be utilized as eight additional single-ended inputs when backup processing is also implemented. (See Section 6.2.1.)

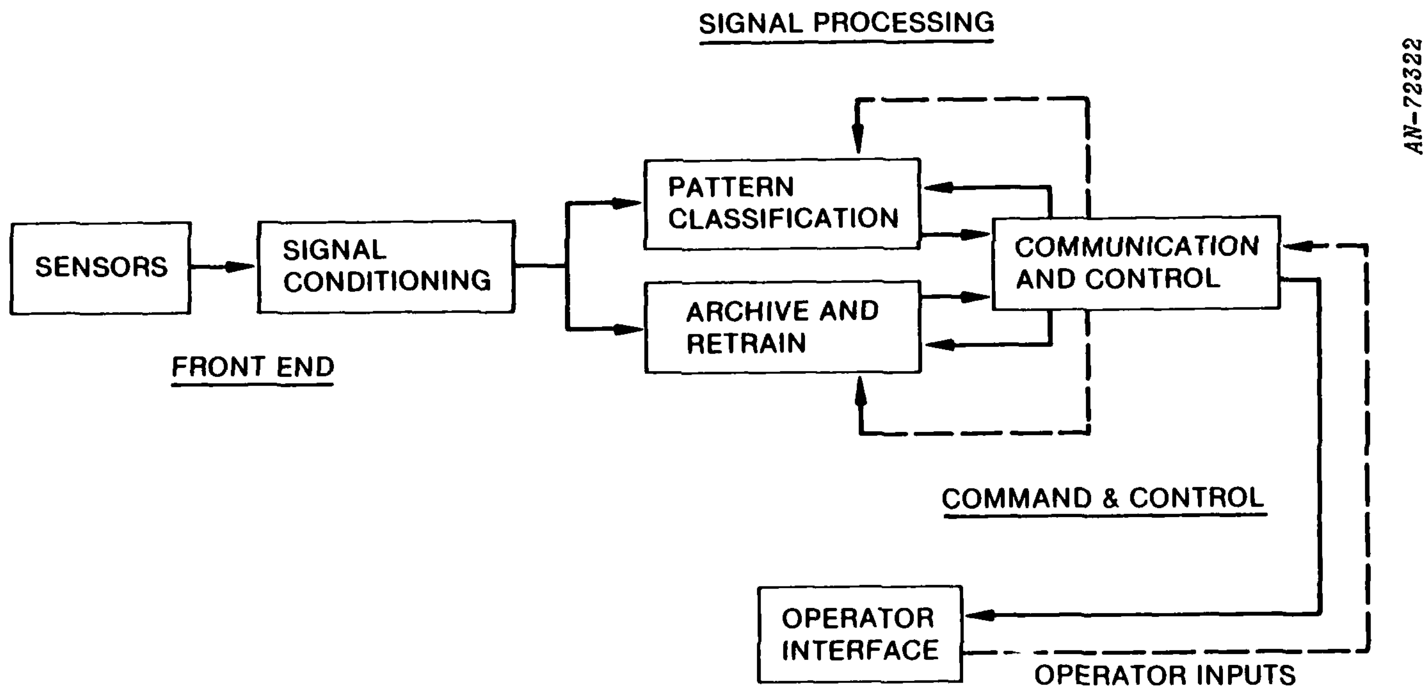


Figure 9. Overall system block diagram.

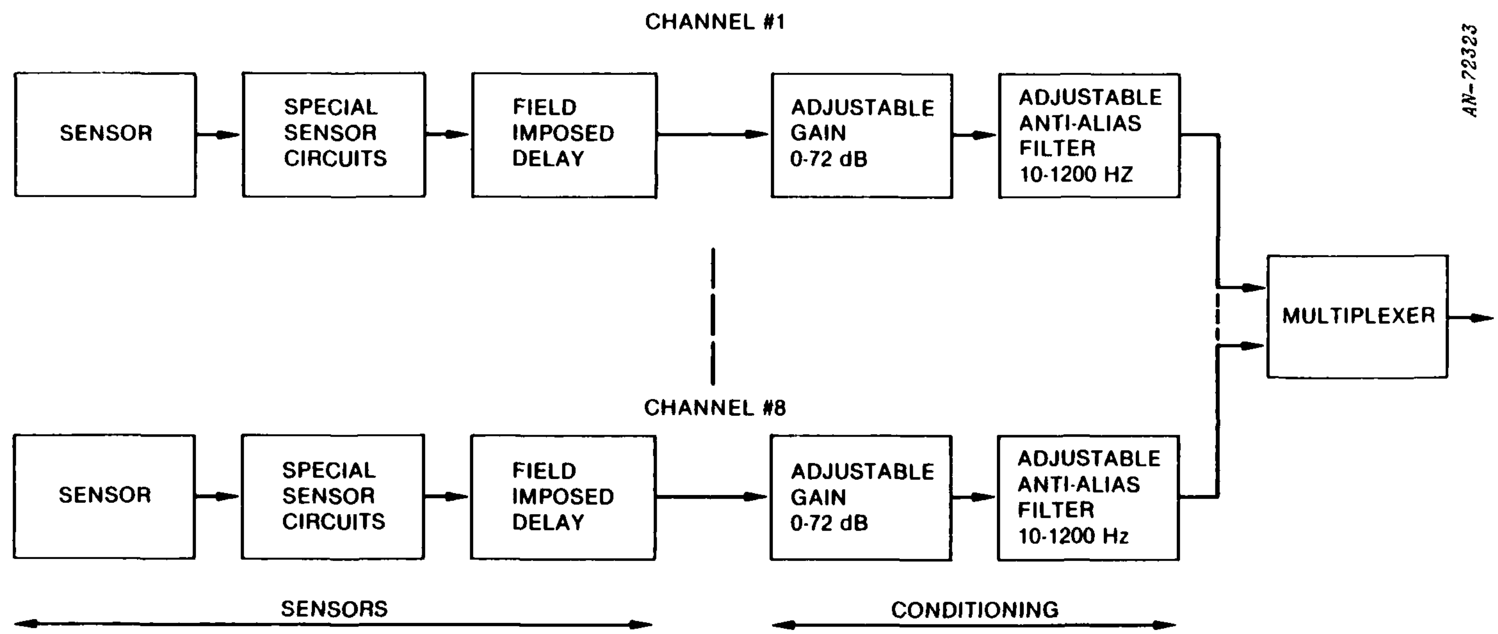


Figure 10. Front end block diagram.

Following the sensors, provision is made for special circuits which may be required by particular sensors. An example is the demodulator needed by the RACON. Since these circuits are tailored to particular sensors, they will be located in special boxes external to the main node circuitry.

The sensor suites from which data bases were derived during Phase IV had sensors physically located such that all responded at nearly the same instant of time. Thus, there was no need to consider field imposed delays and processing could be optimized based upon assumed simultaneous response. This will probably not be the case for Phase V, and hence field delays are included as a part of the system, since they are a major consideration in the signal processing. These follow the special circuits (although functionally they may be inserted at any point prior to the processing).

For conditioning, a wide range of gain is planned so that levels encountered from most any sensor can be matched to the processing. Following the adjustable gain are low-pass filters, used for anti-aliasing, which will have sufficient range in cutoff frequency to handle any of the presently envisioned sensors.

The multiplexer shown in the figure is discussed in conjunction with A/D conversion in Section 6.3.1. Table 5, which follows, summarizes the parameters for Phase IV and those anticipated for Phase V.

6.2.1 Backup Processing

The backup processing concept, overlaid on normal processing, is shown in Figure 11. The dashed lines are the backup portion. In this diagram, portions of three adjacent nodes have been included and are labeled A, B, and C. The inputs from the sensors to the normal signal conditioning are tapped off and used as inputs to backup signal condi-

Table 5. Front end structure.

PHASE 4*				PHASE 5**			
SENSORS	SPECIAL CIRCUITS	A-A FILTER CUTOFF	FIELD DELAYS	SENSORS	SPECIAL CIRCUITS	A-A FILTER CUTOFF	FIELD DELAYS
SPIR	—	7 HZ	NO	SENTRAX	—	10 HZ	YES
RACON	DEMODULATOR	30 HZ	NO	RACON	DEMODULATOR	10 HZ	USE PHASE 4 SIGNATURES
MILES	—	200 HZ	NO	MILES	—	200 HZ	YES
GEOPHONES (NOT USED)	—	200 HZ	YES	FPS FENCE	ENVELOPE DETECTOR	200 HZ	YES
				GEOPHONES (UNDER STUDY)	—	200 HZ	YES

*DATA BASES
- EGLIN TAPES
- GRC SENSOR FIELD

**DATA BASES
- VICKSBURG
- CRREL

AN-72327

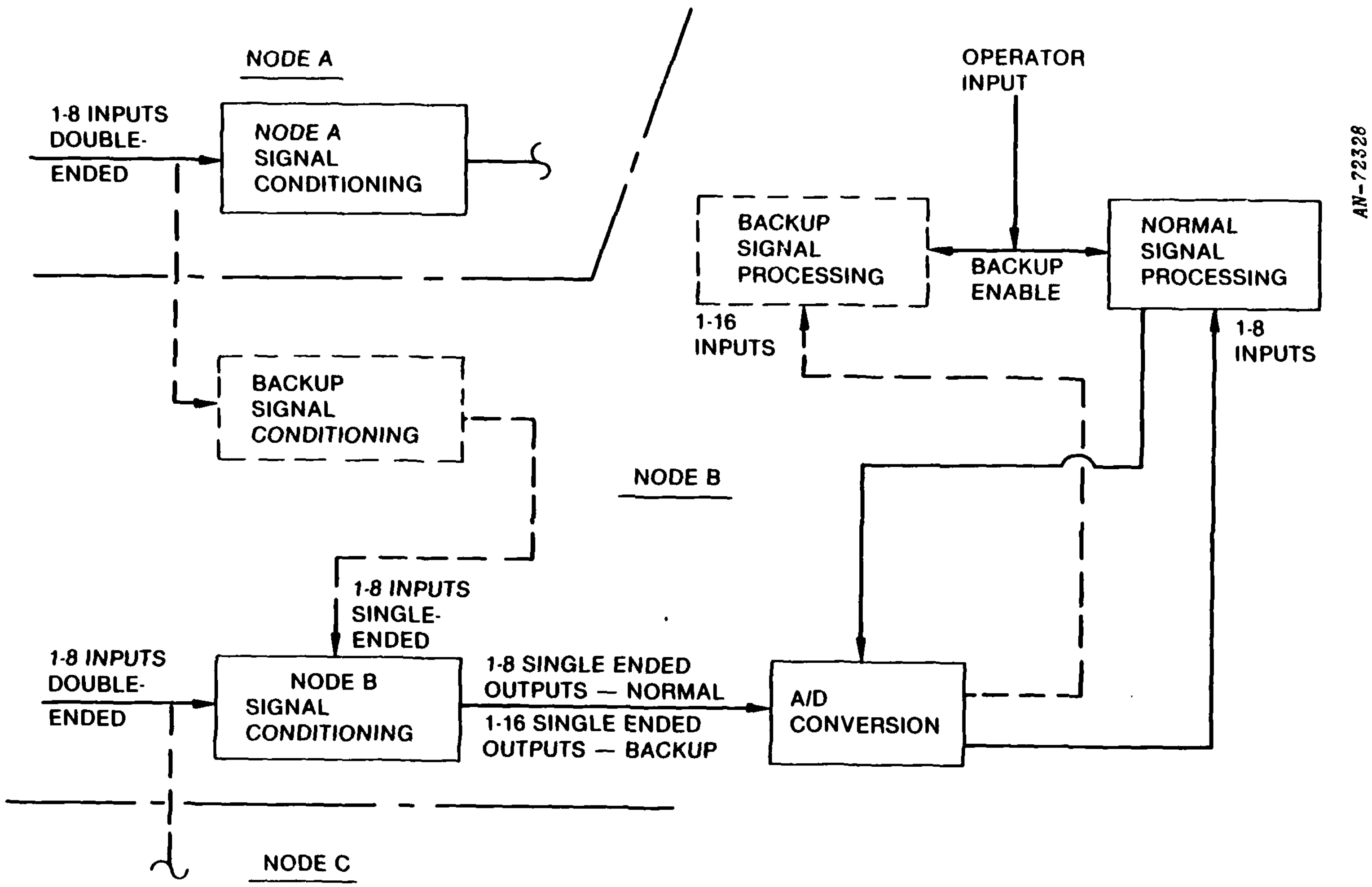


Figure 11. Backup processing block diagram.

tioning (see Node B). The output of the backup signal conditioning is applied at the monitor input of the normal (Node B) signal conditioning, and the output of that conditioning is either 1-8 single-ended outputs or 1-16 single-ended outputs depending whether processing is normal or backup.

A/D conversion must be switched to sample a larger number of channels and, since more channels need to be processed, the processing system must revert to a simpler form of processing to detect an intruder. This switch to backup processing and to a new sampling routine for a node pair in backup processing is activated by the operator when a node failure is recognized. (Note that all other nodes continue to operate normally.)

The diagram would repeat for backup processing between Nodes B and C. Thus, the cost of backup processing will be an additional conditioning board for each node in which it is implemented.

6.3 SIGNAL PROCESSING

Signal processing has been divided into pattern classification, and archive and retrain. The pattern classification portion of the signal processing system is shown in Figure 13, while the block diagram for archive and retrain is in Figure 14. A/D conversion, which is shared by both the pattern classification subsystem and the archive and retrain subsystem, is shown in Figure 12.

6.3.1 Analog to Digital Conversion

The analog to digital conversion circuity (Figure 12) is located on the intel single board computer and will be unchanged from Phase IV. However, the parameters of the conversion system and the manner in which it operates is important to understand since it heavily impacts the

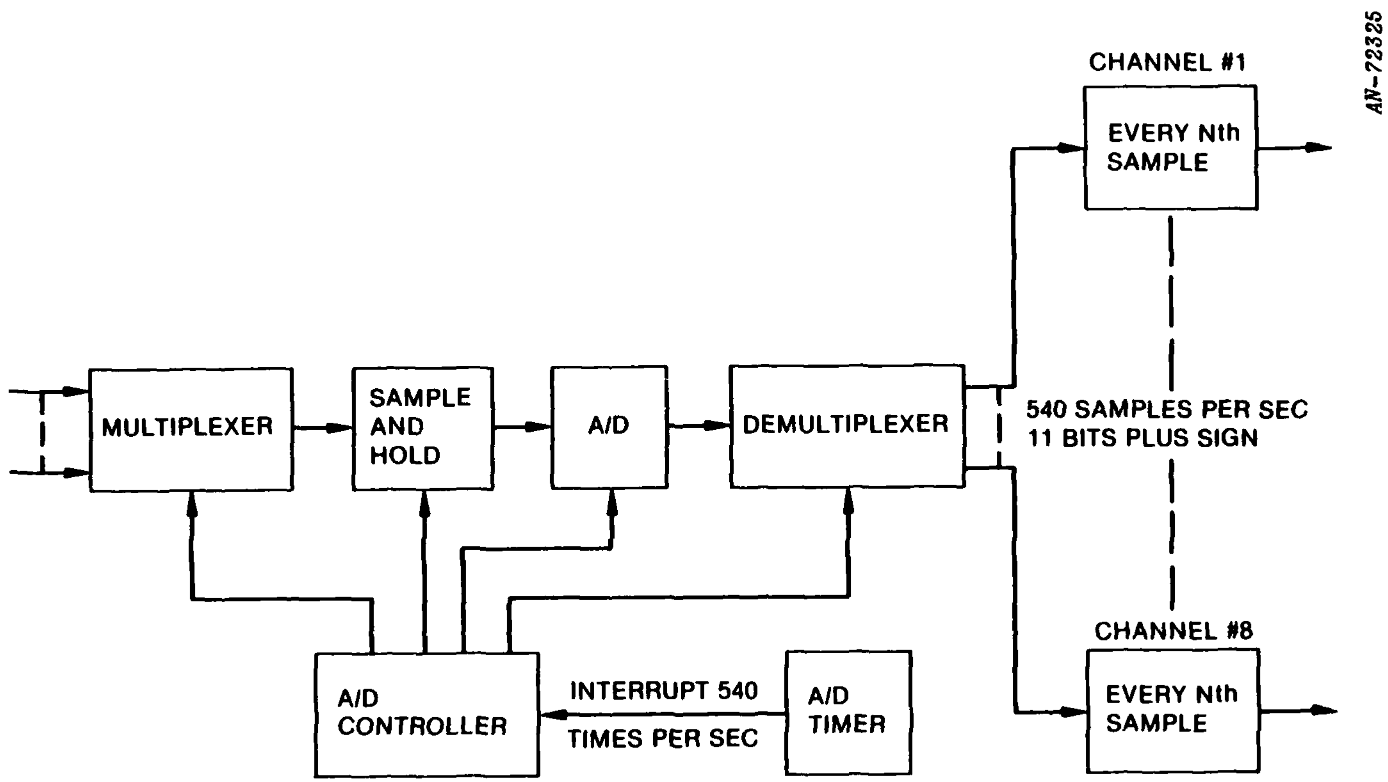


Figure 12. Analog to digital conversion.

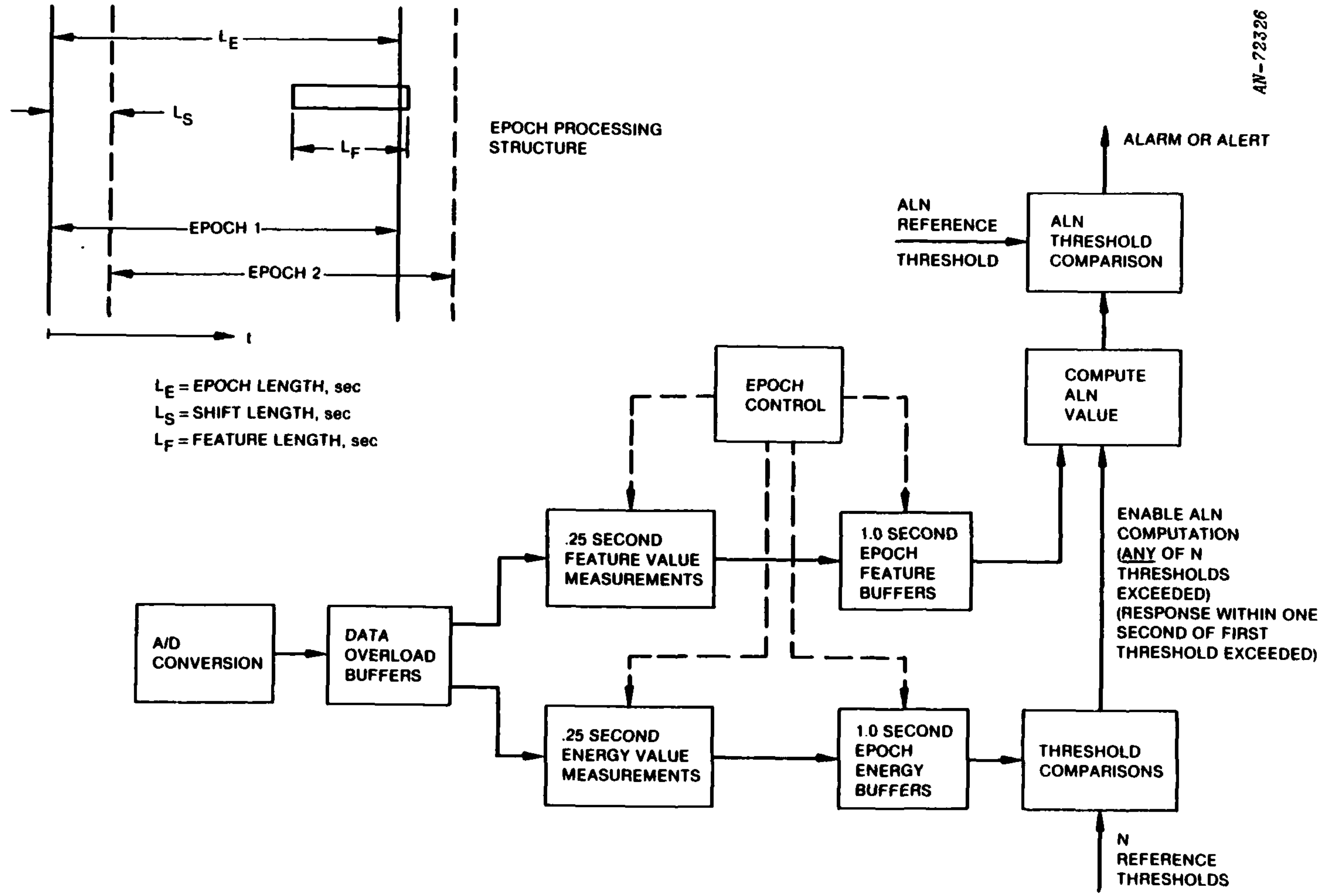


Figure 13. Signal processing for pattern classification.

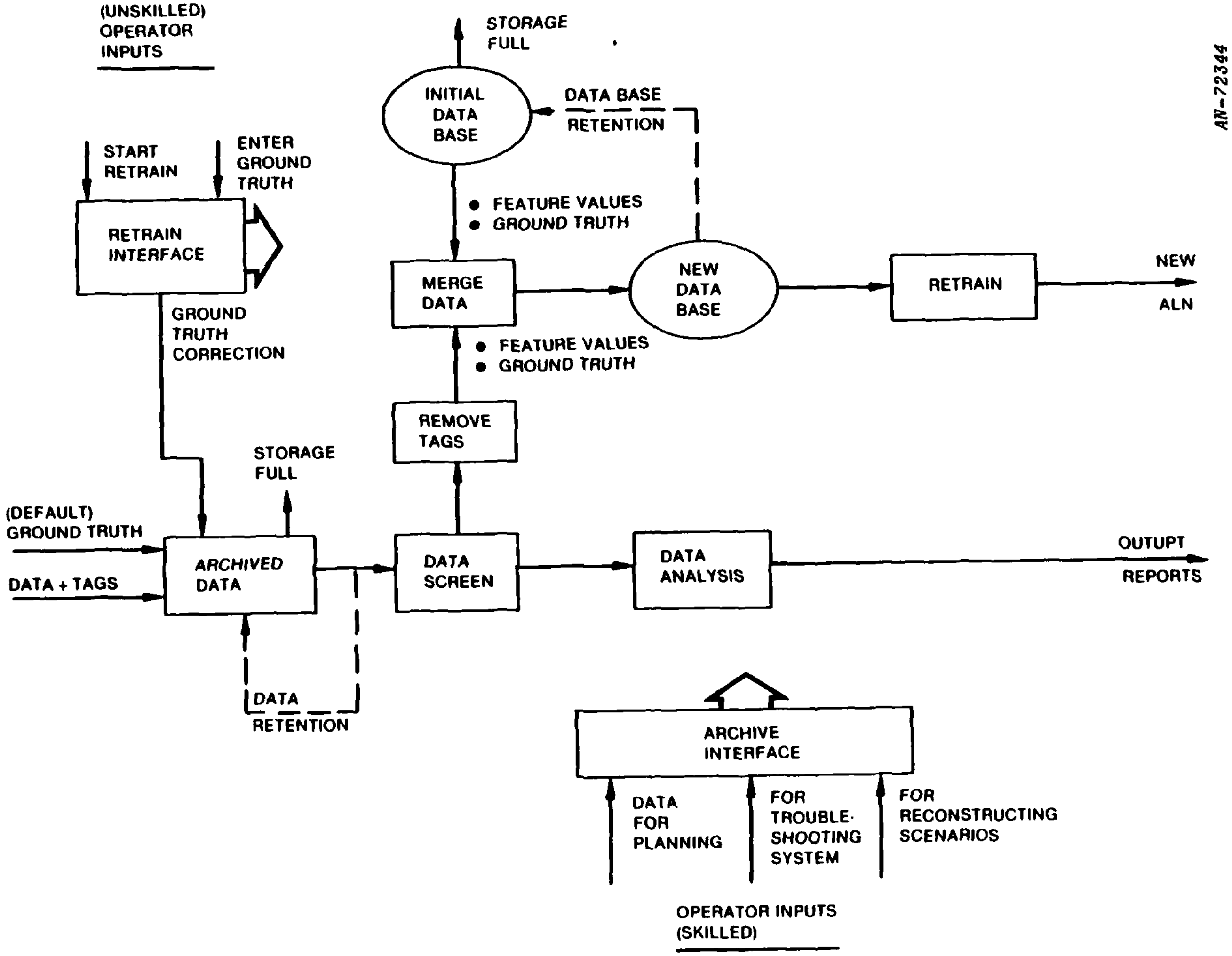


Figure 14. Archive and retrain.

signal processing. An on-board hardware timer initiates data collection by first interrupting the regular processing. This timer is derived by counting a 1.23 MHz clock down to 540 interrupts or samples for each second. Whenever this occurs, the multiplexer is then driven through each channel programmed for sampling. Channels may be sampled in any sequence and at 540 samples per second, or any submultiple of 540 samples per second. Fifty microseconds are required, per channel, for sample taking. A sample consists of 11 bits plus one bit per sign.

The multiplexer is followed by a sample and bold, the conversion, and a digital demultiplexer, all driven in synchronism. (Note that the system actually allows selection of any number of channels in any sequence up to sixteen. Eight of these are reserved for backup processing.)

When eight channels are sampled at 540 samples per second, the total time out of each second which is allocated to data collection is $540x8x50x10^{-6}$ or .216 seconds. This leaves approximately 3/4 of a second out of each second for signal processing tasks, and also implies a need to buffer the data at the input to signal processing.

6.3.2 Pattern Classification

Figure 13 shows the pattern classification. It begins with A/D conversion, which was described in the preceding section, followed by buffers which collect data, and store data overloads during times of heavy processing.

Data in this subsystem is processed in frames or epochs. Epoch processing requires the definition of two key parameters. The first is epoch length. This is the length of the time series that is collected

for each processing step. The second parameter is shift length. This is the distance along the time series that the system moves before processing the next epoch. In this system, these parameters were chosen based upon the features selected, and upon the desired time response, as 1 second and 1/4 second, respectively. Thus, four epochs are processed per second, which means that each piece of data enters into the processing four times before being discarded. Depending upon the length of a feature relative to the epoch and shift lengths, the same feature may be present in one or more epochs.

The processing is shown as dividing into a feature channel and an energy channel in Figure 13. Both channels are locked to the epoch timing. Features are measured in every epoch, but are not input to the ALN computation until one of the sensors has exceeded an energy threshold during that epoch. It is assumed, in Figure 13, that all sensors being monitored are collocated and respond nearly simultaneously to an intrusion. Thus, the response of any one sensor is sufficent to activate the processing. This is the function of the threshold comparison in the lower right hand corner of the block diagram. (While energy values are used to compare against thresholds, these values can also be used as features.) Once a threshold has been exceeded, a value is computed within the ALN, using feature values measured during the epoch for input, and the output value of the ALN is compared against a second threshold. If the threshold is exceeded, an alarm is activated, if not, an alert is activated.

From the standpoint of multi-sensor integration, the most desirable situation is to have all sensor signatures occur nearly simultaneously, and all features occur in the same epoch. Non-simultaneous signatures occur when the sensors in a field are physically separated. Then, depending upon the intruders' method of entry into the field, the sequencing of signatures may vary greatly and will not necessarily be known beforehand. When this situation is present, the first task is to

locate each signature. This is most easily accomplished by setting an energy threshold for each sensor, and then recording the epoch at which each threshold is crossed.

After measuring this separation between signatures, the epochs must somehow be aligned in order to appear to the processing to be physically aligned. This may be done in any of three ways. First, the sampled signatures themselves may be aligned by adjusting the relative timing of the data, before feature measurement; or second, the features may be held in expanded feature buffers and aligned on the basis of epochs; or third, ALNs may be implemented for each physically separated sensor, and the output ALN values then may be aligned by epoch and input into a combining ALN. The response time for this system configuration can be no faster than the time required to recognize the last signature and to complete the processing.

6.3.3 Archive and Retrain

The archive and retrain portion of the Physical Security System is shown in Figure 14. In order to explain the diagram, it is necessary to define certain terms which are used on the diagram or in the text which follows. These definitions are:

Unskilled Operator. An unskilled operator is one who will be capable of making handwritten entries in a log book, which describe the parameters associated with alarms. This operator will also be able to transfer these entries into the system, via the keyboard, in response to prompts issued by the system.

Skilled Operator. A skilled operator is assumed to have sufficient knowledge of the system to be able to carry out any of the functions assumed for archiving and retraining. For any of the functions, use of the system would be augmented by instruction manuals and by system prompts.

Off-Line. Operation of the system in an off-line manner implies one of two procedures. Either the physical security system is shut down in terms of intrusion detection, and operated solely for the off-line function being performed, or the off-line function is performed on a separate and dedicated piece of equipment, which may or may not be connected to the physical security system.

On-Line. Operation of the system in an on-line manner is taken to mean that the function being performed can be done on the system at the same time that the full set of physical security functions are being performed.

Operator's Log. The operator's log is assumed to consist of data sheets which are ruled into columns with appropriate headings so that if the operator enters events prompted by the headings, he will have tabulated all data needed for ground truth entry into the system.

Ground Truth. Ground truth is the true classification of an event.

The data input for the system is shown on the lower left in Figure 14. It enters storage (the block labeled "Archived Data") with a set of tags supplied by the system with data that has alarmed or alerted the system. The parameters archived are: (a) raw data from sensors over the alarm or alert epoch; (b) feature values from sensors over that epoch; (c) ALN value (or values); (d) alarm or alert; (e) source node number; (f) time and date; and, (g) default ground truth. The primary purpose for collecting this data is for retraining ALNs; however, having collected the data, it becomes valuable for other purposes as well. The major uses which are foreseen for this data are listed below, and are accessed through "Data Screen" and "Data Analysis" in Figure 14.

Retrain ALNs. The major purpose for archiving data is to train new ALNs whenever this becomes necessary. Insertion of ground truth into the system in order to prepare for retraining would be done by an unskilled operator. It will be accomplished off-line, and all ground truth entries will be made just prior to retraining.

Reconstruct past scenarios. The security task is primarily a monotonous task, punctuated by rare times of heavy activity. It will be highly desirable to have the ability to out-sort data collected during these periods so that it can be examined in detail. It is assumed that this out-sorting would not occur often, and that it would be done only by a skilled operator, off-line.

Develop statistical information on the content of the data base. This information will be valuable for planning future courses of action. Such courses of action might include sensor effectiveness studies, determination of the need for retraining, or determination of whether the data base is adequate for retraining. It is assumed that this would be done only by a skilled operator, and that it would occur off-line.

Troubleshooting system, especially sensors. The archiving capability also offers a powerful method for calibrating and recording the performance of individual sensors, or of the entire sensor field over a period of time. This implies the ability to be able to out-sort signatures from specific sensors, specific nodes, or specific time periods. This will be done off-line, and only by skilled operators.

Two possibilities exist for retraining and are differentiated mainly by how and when ground truth is entered. In the first, ground truth is entered directly into the system, rather than into an opera-

tor's log, and the entry is made as soon as possible after the event has occurred and been classified. In this way, the data base is kept current, and the system can measure its own performance as a function of time and determine the need for retraining based upon a stored set of rules. The disadvantage with this scenario is that it requires a more highly competent "unskilled operator", and system performance losses may result from sources other than new or modified nuisances.

In the second scenario, system statistics are monitored periodically by a skilled operator to determine the need for retraining. Only true intrusions need be recorded by the unskilled operator, and this would be done in handwritten form in an operator's log book. It is this second scenario that is shown in Figure 14, and the rationale for needing to record only intrusions follows below.

There are 4 possible combinations of alarms and alerts, intruder and non-intruders. The archived value will originally be set to the system default value. At some point prior to retraining, the correct ground truth value must be entered by the operator. Since the majority of events which occur are expected to be non-intruder/nuisance events, if the system default is Alert, few changes to ground truth should need to be made; only true intruders need to be entered in the log.

System Output:	ALERT	ALERT	ALARM	ALARM
True Event:	INTRUDER	NON-INTRUDER	INTRUDER	NON-INTRUDER
Archived Ground Truth (Default):	ALERT	ALERT	ALERT	ALERT
Actual Ground Truth:	ALARM	ALERT	ALARM	ALERT
Change?:	YES	NO	YES	NO

Thus, default ground truth is entered in the system along with the data (Figure 14), and the operator makes the needed corrections through the interface to retrain.

Data may be extracted from the archive storage and sorted against any of several parameters. These will include screening for a particular period of time, for particular nodes, for event types or for sensor types. When data is screened in this fashion, either for reporting purposes or for adding to the data base, the full data set, upon which the screening took place, remains in storage. Removing data from archive storage will be a separate operation which may be as simple as erasing the oldest data, or portions of the archive may periodically be removed from the system and stored separately.

It is anticipated that data will be moved out of archive storage, to build a new data base, without special screening, since this would probably bias the data. The data moved from archive storage must first be stripped of tags before it is merged with the existing data base to form a new data base. The new data base is then retrained as the initial data base. Provisions must also be made for separately removing data from the initial data base, again perhaps by erasing the oldest data. The new data base can be used at any time to retrain in order to develop a new ALN. (This new ALN will be limited to a feature list included in retrain, and the capability to turn off selected features will also be present.)

6.4 COMMAND AND CONTROL

6.4.1 Communications

Local area networks provide high bandwidth communications over a limited geographic area. The local area network for this perimeter security system has been implemented with a fiber optic communication

channel. The inherent bandwidth and security of a fiber optic transmission medium makes it ideally suited for use in this application.

Figure 15 shows the communication system architecture. The site perimeter is divided into sectors, each of which has a set of sensors connected to an independent processing node. The nodes are arranged into a double ring topology, with data being transmitted in opposite directions simultaneously. This enhances system reliability and security and aids in reducing the number of errors during transmission. The nodes communicate over a fiber optic link, by means of local area network controllers which are present in each node.

Buried fiber optic cables are used as the communication channel in this network. The system response time requirements and the signal processor resource sharing architecture dictated a large bandwidth for the channel. These factors, in addition to requirements for security, resistance to electromagnetic interference and reasonable costs for large perimeters, made fiber optic cables the logical choice.

Each of the nodes is connected in the network by means of a standard interface. This interface consists of an electrooptical modem and an intelligent network controller. Two independent modems and controllers are present in each node to service the two data channels.

The electrooptical modem provides the conversion of electrical to optical and optical to electrical signals for transmission and reception of signals to and from the fiber optic channel.

The controller allows the transfer of information from one node of the network to another node without the intervention of the host processors. The controller handles all protocol, data packet formation, recovery from transmission errors, transfer of data into and out of the

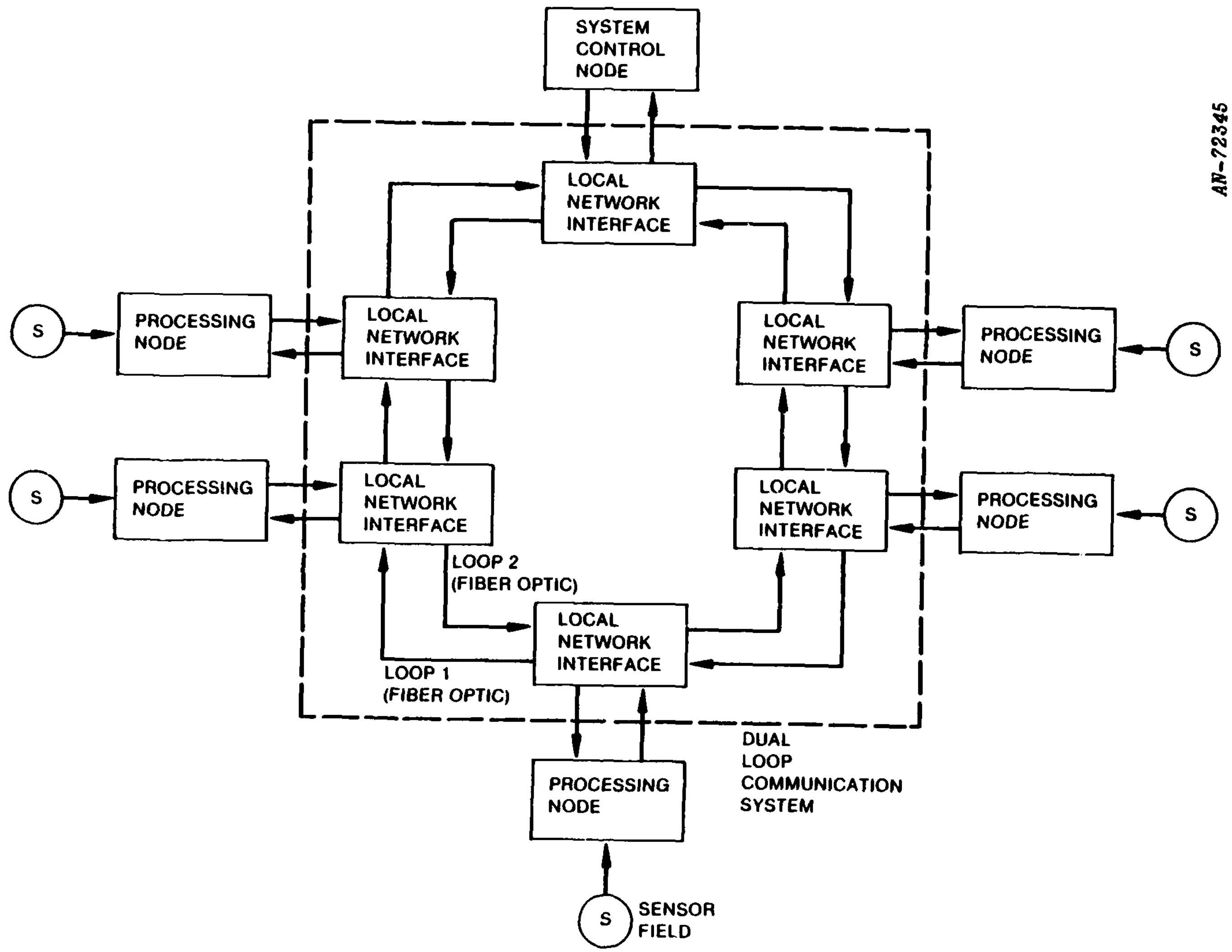


Figure 15. Communications architecture.

host computer memory, and notification of the host when a transaction has been completed.

The network uses a modified SDLC protocol. System control is achieved by polling which is under supervision of the system control node. The local area network controllers (LNCs) in the system control node are configured as masters, and all others are configured as slaves. The master LNC boards use a polling list to determine the sequence in which they poll the nodes, and the amount of time allotted to a node during which it may start a transaction when it is polled.

When a node is polled, it temporarily takes control of the network and can transmit to any other node in the network. This is a modified token passing system since the token is passed by the system control node.

Upon completion of its transaction, the polled node notifies the system control node, and network control is passed to the next node on the polling list. This provides a more efficient use of channel capacity than a fixed polling cycle, and reduces system delay time. If one of the nodes is likely to have more transactions to perform than the other nodes, it may occur in the polling list several times.

Data are transmitted over two fiber optic loops in clockwise and counterclockwise directions by means of an optical transmitter. These data are sent at a rate of 1.5 Mbits/s. An optical receiver converts the optical signal to an electrical signal which is demodulated by a phase locked loop to recover both data and clock information.

The local area network controller provides the interface with the host computer at each node for each direction and passes data into and out of the Multibus system memory by direct memory access. It queues transactions, formats messages, positively acknowledges message packet

reception, and is able to automatically retransmit data packets transmitted in error.

The network topology requires a repeater so that each node is able to selectively remove a message from the ring or to pass it to the next node. In conventional systems, each node stops the message long enough to determine whether it was the message's destination before retransmission. This adds to system delay time. In order to eliminate that delay in our system, the message is automatically retransmitted at each node while the node's network controller determines whether the message was intended for the present node.

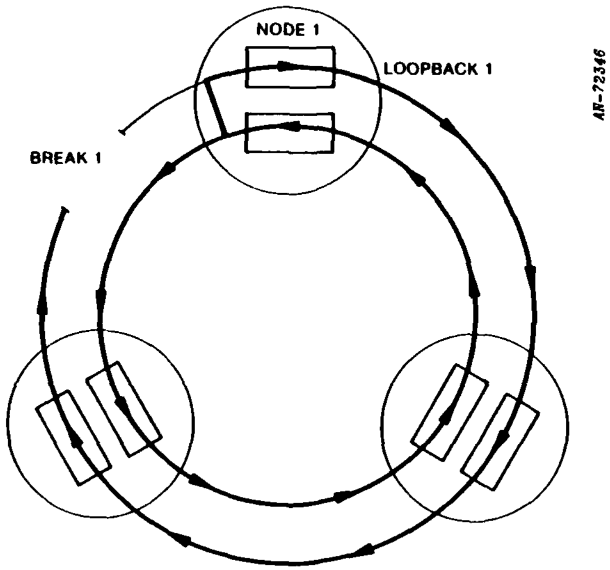
Since each node retransmits the messages automatically, the messages must be prevented from traveling around the loop indefinitely. This is achieved with a transmit/repeat switch which breaks the ring at the transmitting node and removes the message from the ring when it reaches the original sender. When a transmission has been completed, the switch returns to the repeat position, thus restoring ring integrity.

Detection and correction of fault conditions have been incorporated in the network operation. For this purpose, the transmitting node sends identical messages in both directions. If the transmitter does not set an acknowledgement of message reception without error from the destination node, the transmitter retries a preset number of times. Once a message has been transmitted successfully on one of the loops, no further retries are necessary, even if the transmission on the other loop was not successful. The receiving node processes the first of the two duplicate messages that arrives successfully, and disregards the other.

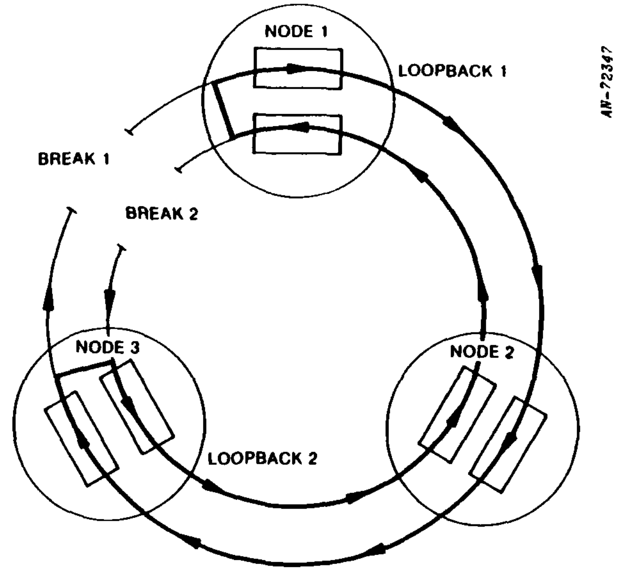
Line monitoring is performed by a signal level transition detector consisting of a counter which counts local clock cycles, and is reset to

zero with each transition coming from the previous node. Since the data traveling on the ring are biphase modulated, transitions are occurring at the clock frequency even when no messages are traveling around the loop. If a node fails or an optical fiber is cut, no transitions will occur at the next node. The counter therefore does not get reset to zero, and since the local clock is still present, the counter contents will reach an unacceptably high value. This will cause the ring to be broken and to loop back, thus restoring ring integrity. At loopback, the input of the channel where transitions were lacking, is connected to the output of the channel in the other direction at the same node. The first time loopback occurs in a channel, polling in that channel's direction is terminated,in order to avoid duplicate messages being sent on the same ring. Figure 16 illustrates the situation where two breaks occurred in the system, thus causing two instances of loopback. As shown in Figure 16(a), a break in one of the two rings leaves the other ring operational regardless of whether the loopback feature is implemented. The value of loopback comes into play when breaks occur in both rings, which could result in complete breakdown of the network. Instead, the loopback response to the two breaks reconfigures the network into a single, continuous loop, as shown in Figure 16(b).

The last fault condition is that of a chattering node, which occurs when a node does not relinquish the data channel once it starts transmitting, but continues transmitting meaningless data. This could be due to a malfunction either in the LNC section, or in the host processor. The condition is detected in hardware by counting the number of transitions present in a given message at the output of the LNC 5180. From the maximum possible length of the messages being sent in the network, it can be determined whether a channel at a given node is transmitting for too long a time. When this condition is detected, the transmit/repeat switch for that direction is set to repeat permanently. This effectively takes that node out of the network in the channel being considered, since the transmit/repeat switch must be in the transmit



(a) Single Failure



(b) Two Failures

Figure 16. Loopback.

postion for a node to respond to a poll, or to send a message. On the next poll cycle in that direction, the node will not respond, thus alerting the control node that a failure has occurred. The ring integrity remains, and since the communication sections for the two directions are independent, the node will still respond to commands through the remaining communication channel.

6.4.2 Operator Inputs

STARTUP SEQUENCE

The startup sequence of events occurs when the system is powered up. When the basic and enhanced nodes are powered up, they automatically start executing code contained in nonvolatile memory of the erasable, programmable, read-only memory (EPROM) type.

The code in EPROM waits indefinitely for any of three message types: sofware download (type 2); condition check (type 3); or, node reset (type 9).

The software download messages place some amount of code, typically about 30 bytes at a time, in the memory of either the basic processor board or the enhanced processor board.

The condition check message causes a node to reply by sending a condition response message (type 4) to the central node indicating whether software download, configuration download, and/or network download have been successfully completed.

The node reset message causes the node to jump to the beginning of EPROM code and initialize itself as if the node had just powered up, and again wait for software download.

When the central node is powered up, it waits for the system operator to command it to begin system initialization. The sequence of events that then occurs is as follows:

1. Central node downloads basic software to both basic and enhanced nodes.

2. Basic node starts executing its downloaded code, but does not start operation; that is, it does not start processing sensor signals. It can receive and transmit messages at this point, however.

3. Central node downloads enhanced software to enhanced nodes.

4. Enhanced node starts executing downloaded code in both the basic and enhanced processors, but, similarly to the basic node, does not start operation.

5. Central node downloads operational parameters via the configuration message (type 1) to both basic and enhanced nodes.

6. Central node downloads the network, or decision model, to enhanced nodes.

7. Central node sends a condition check message to both basic and enhanced nodes.

8. Both basic and enhanced nodes send a condition response message to the central node, where the contents of the messages are displayed to the system operator.

IDLE AND ACTIVE STATES

At this point, the system has been initialized but none of the nodes have been commanded to start operating; they are all in the idle state. The central node now continues in its sequence of events:

1. The central node sends a Start Operation message (type A) to the enhanced node, causing its basic processor to start processing sensor signals and its enhanced processor to accept and process data messages from any basic node or from its own basic processor.

2. The central node then sends a Start Operation message to the basic node, causing it to start processing sensor signals.

The system is now operating in the fully active state.

ACTIVE STATE WITH ALARMS OR ALERTS

The following sequence of events occurs when the system is in the active state and the sensors are stimulated by either an intruder or a non-intruder:

1. If the sensors being stimulated are processed by a basic node, that node will send a set of data messages (type 5) to the enhanced node. If the sensors are processed by the enhanced node, the basic processor in the enhanced node will send a set of data messages to the enhanced processor in the same node; the data messages will not be transmitted over the communication system, but will be transmitted internally over the bus connecting the processor boards.

2. If the enhanced node determines that the source stimulating the sensors is an intruder, it will send an alarm message (type FF) to the central node.

3. If the source stimulaing the sensors is not an intruder, the enhanced node may, depending on current operational parameters, send an alert message (type FE) to the central node.

RECONFIGURATION

The system operator may alter the operating characteristics of both the basic and enhanced nodes during normal operation. The following messages are used to do this:

1. The network, or decision model, in the enhanced node may be changed by causing the central node to send it the network download message (type 7).

2. All other operational parameters in either the basic or the enhanced nodes may be altered by sending them the configuration message (type 1).

These message types are the same ones that are used at system initialization. They may be used again at any time during normal operation of the system.

ERROR CONDITIONS

Three different message types can be used to determine if an error condition exists in the basic or enhanced nodes:

1. The system operator can command the central node to send a condition check message (type 3) to the nodes in order to

receive condition response messages (type 4) back and have their contents displayed.

2. Some illegal conditions encountered by the basic or enhanced nodes can cause them to send log messages (type 6) to the central node for printing or display to the operator. These are text messages giving a brief description of the problem encountered.

3. The communication software aided by communication hardware in both the basic and enhanced nodes will send a loopback message (type 8) to the central node whenever it detects a lack of transitions from a neighboring node. It will then perform a loopback operation to isolate the faulty neighbor node from the rest of the network.

ARCHIVE AND RETRAIN

Operator inputs to archive and retrain were discussed in Section 6.3.3.

The final section of this report develops the plans for implementing the full set of system functions just described in this section.

SECTION 7
PLANS FOR CONTINUING WORK

7.1 SYSTEM UPDATE

The system presently at GRC will undergo additional development so that it matches the description in Sections 3 and 5 of this report. This effort will include:

- o Updating the fiber optic modem for dual loop operation.
- o Activating dual loop operation for three nodes.
- o Activating and testing frequency domain operation.
- o Activating and testing archiving.
- o Activating and testing retraining.
- o Include backup processing (for node failure).

In addition the Wicat system will be replaced with an IBM-PC. This will allow dual loop operation and should provide better system capatibility (8086 to 8088) and better software support from IBM.

7.2 TWO SYSTEMS

Two systems are needed during Phase V, one to be used for development testing at GRC, and one to be fielded for tests at various Government sites.

The system presently at GRC will continue to reside there and be used for development purposes. A second functionally equivalent system will be constructed for field use.

7.3 ADDITIONAL SENSORS

Features from two new sensors will be examined for inclusion in the ALN classifier. These two sensors will be an E-field sensor and a fence sensor. In addition, promising combinations of these two sensors with the RACON sensor, the MILES cable, the SPIR cable, and the geophones will be explored. Once a "best" sensor combination is arrived at, reduced ALNs, ALNs which would operate if one or more of the sensors failed, will be examined.

7.4 SITE ADAPTABILITY

Changes associated with new site locations will be taken into account through retraining. Environmental changes are also important if they significantly alter the performance of the sensors. These changes may be either long or short term. For long term changes (winter to summer), a new data base may be collected, and the system can be retrained. Where changes are of shorter duration (rain to clear), the data base can contain samples from a range of conditions and a broadly applicable ALN can be produced. It is not planned to directly sense the environment and include this in the construction of the ALN.

7.5 BACKUP PROCESSING

The full dual loop communication system has excellent fault recognition and recovery designed into it. A similar capability should be built into the processing nodes and the sensing system.

The present system A/D converter has 16 inputs. Eight of these are occupied by sensors (1-RACON, 1-MILES, 1-SPIR, and 5-Geophones).

Backup processing, the switching of a second adjacent sensor field into a single node, would require eight additional inputs. This may be in conflict with Section 7.3, the adding of additional sensors to the system. Therefore, to demonstrate the feasibility of backup processing, the system will either be configured such that when a node fails, the six most important adjacent field sensors will be switched, and simple threshold processing will be performed on all 16 of the inputs, or some number of the geophones will be removed from use in the sensor field.

There still remains the problem of testing for proper sensor operation. This may be done by training a special set of ALNs to recognize normal inputs from the sensors when no signal is present, that is, when none of the simple energy thresholds in the processing nodes have been exceeded. When a condition is realized which lies outside of normal operation an alarm indicating "sensor out of range" could be sent to the display console. This would also activate some form of reduced processing (yet to be determined) in the basic node. Note that this does not address the situation in which sensor performance gradually degrades.

7.6 TIMING MEASUREMENTS

Procedures will be built into the GRC development system for making internal measurements.

Timing software will be overlaid on the processing and communication software to make timing measurements. The results of these timing measurements will be available as a display at the control console and may include:

- Time spent in major processing tasks.
- Queue depth or waiting time on all major system queues.
- Data rates past key points in the system.

In addition the system should have the ability to collect data for developing a complete system ROC curve.

7.7 EXPANDED DISPLAY CAPABILITY

The system will have additional display capability, for ease of trouble shooting and for graphic demonstration. This may include (but not necessarily be limited to):

- An indication of the system mode.
- An indication of any non-operational system elements, including sensors.
- A graphic indication of the retraining progress.
- The contents of key selected buffers.
- A demonstration of environmental adaption.
- A view of the test field.

7.8 TEN NODE SIMULATION

The system will demonstrate the capability of operating with up to ten nodes.

The physical systems, both GRC demonstration and the field system, will be constructed as three node systems. In addition, the communication traffic for up to seven additional nodes (with the number selectable) will be simulated. This will be done only on the GRC system and the timing measurements will be capable of handling this additional load.

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